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PHOTOLUMINESCENCE OF GALLIUM ARSENIDE ENCAPSULATED WITH ALUMINUM AND SILICON NITRIDE FILMS

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by

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Report SF23

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Aluminum and silicon nitride films were deposited on lightly doped n-type GaAs:Si by low energy ion beam sputtering. The films showed no signs of deterioration when annealed at 900°C, and the GaAs photoluminescence spectra showed new features only at the higher annealing temperatures.

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PHOTOLUMINESCENCE OF GALLIUM ARSENIDE ENCAPSULATED WITH ALUMINUM AND SILICON NITRIDE FILMS

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ABSTRACT

Aluminum and silicon nitride films were deposited on lightly doped n-type GaAs:Si by low energy ion beam sputtering. Mechanically the films were stable at annealing temperatures above 900°C. In contrast to bare GaAs and previously reported encapsulation with Si_3N_4 where the 1.36 eV line appears at relatively low annealing temperatures, there was no change in the photoluminescence spectrum until the samples were annealed at 800°C in the case of aluminum nitride and 900°C for silicon nitride.

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Gallium arsenide that is doped by implantation must be annealed to relieve structural damage. One technique for preventing the loss of arsenic during the annealing process is to encapsulate the GaAs surface with a deposited dielectric layer that can withstand high temperatures. In this paper, we report the results of encapsulation with silicon and aluminum nitride films as revealed primarily through photoluminescence (PL) studies.

Characteristic of what happens at a GaAs surface that is not encapsulated is shown in Fig. 1. The n-type GaAs used had only a very light doping of silicon (4×10^{15} cm^{-3}) so that there would be a high degree of sensitivity to any changes in the PL spectrum. As reported previously,[1] the initial spectra has only a single near band gap peak at 1.503 eV and is not sensitive to the measurement temperature below 100 K. Upon annealing, however, a distinctive feature appears at 1.36 eV. It is attributed[2] to an arsenic vacancy-silicon acceptor complex, although other authors[3,4] disagree. The lower energy shoulder, in any case, is the LO phonon replica. In our work, the appearance of the 1.36 eV line was first noticable at 500°C annealing and became dominant at 600°C. Additionally, we observed considerable growth of the 1.503 eV line at the same temperature, and visual observation showed that the polished surfaces had become significantly duller.

Considerable effort has been given to developing techniques for depositing silicon nitride,[4-9] and to a lesser extent, aluminum nitride[10,11] for encapsulation purposes. The technique we employ is low energy ion beam sputtering[12] using a neutralized beam, primarily nitrogen, impinging on a pure aluminum or silicon target. Deposition takes place simultaneously

on GaAs and Corning 7059 glass substrates which are rotated during the process. Generally, both target and substrate are lightly sputter etched in situ before deposition; the substrates remain near room temperature throughout the process. The sputter beam energy used most successfully was 800 eV. The AlN depositions used a pure nitrogen beam, while the Si_3N_4 seemed to work best with a 15% admixture of argon. Typical deposition time was 20 minutes resulting in films the order of 800 Å thick. Both the AlN and Si_3N_4 films on glass were quite transparent ($\sim$90% transmission) from 0.3 to 3 μm. Auger analysis showed that the primary impurity was oxygen, having a concentration near 5% in both the AlN and Si_3N_4 films. Other impurities were considerably lower and probably unimportant. Neither the pre-deposition sputter etch or the deposition itself leads to any significant changes in the PL spectrum.

The development of the PL spectrum for the AlN encapsulated GaAs, at successively higher annealing temperatures, is shown in Fig. 2. The same low carrier concentration GaAs is used, and the scale is the same as in Fig. 1. Basically, the same pattern is seen except that 300 additional degrees of annealing temperature are gained before changes begin. In addition to the growth of the 1.503 eV line and the onset of the 1.36 eV peak, we did observe a small feature at 1.40 eV, also seen in other work. Even at 900°C, however, there is no observable visual deterioration (under 400x magnification), no shift in refractive index, no decrease in transparency, and no change in Auger profile. Other AlN samples studied show basically the same PL development, except in some cases the growth of the 1.503 eV line preceeds the onset of that at 1.36 eV.

In the case of Si_3N_4 encapsulation, the PL spectrum remains unchanged until still higher temperatures. As with the AlN films, there are no other signs of deterioration of the Si_3N_4 layers. Figure 3 illustrates the PL onset, omitting the uninteresting intermediate temperatures. This higher temperature onset shows an improvement over our earlier Si_3N_4 results(9) where we saw PL changes at 600°C. The difference, we believe, is due to an increase in our sputter beam energy from 500 to 800 eV and an increase in the nitrogen fraction of the beam.

In summary, we have succeeded in depositing dielectric layers of aluminum nitride and silicon nitride that appear to be useful for the encapsulation of gallium arsenide. We feel that good results are attributed to general cleanliness, predeposition sputter etches, and the proper energy and composition of the beam. We also see some evidence that oxygen impurity in the films may degrade their encapsulation properties, perhaps explaining the somewhat better results with the Si_3N_4, which is slightly more stable chemically compared to SiO_2 than AlN compared to Al_2O_3.

ACKNOWLEDGEMENTS

We wish to thank John Wager for the Auger results and Harry Wieder for several useful conversations. We also acknowledge the financial support of the U.S. Office of Naval Research (Contract N00014-76-C-0976), the Basic Science Program of Seoul National University, supported by USAID, the Scientific and Research Council of Turkey, and the faculty improvement program of Istanbul University.

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FIGURE CAPTIONS

Figure 1. Appearance of 1.36 eV PL line at 90 K when bare GaAs:Si ($n = 4 \times 10^{15}$ cm^{-3}) is annealed at 500 and 600°C.

Figure 2. Onset of the PL features when same GaAs is encapsulated with AlN using ion beam sputtering and then annealed.

Figure 3. Higher temperature onset of PL change when GaAs is encapsulated with Si_3N_4 prior to annealing.

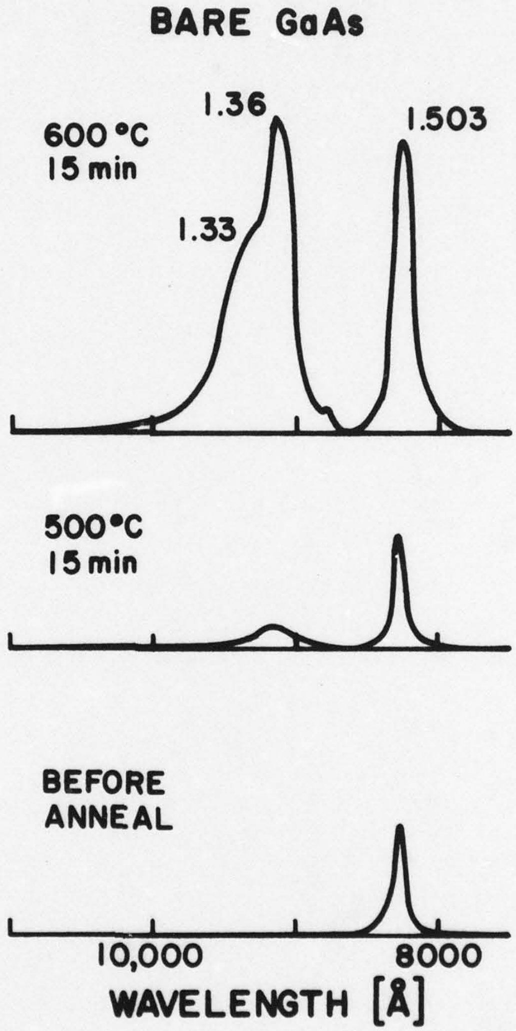

BARE GaAs
600 °C
15 min
1.36
1.503
1.33
500°C
15 min
BEFORE
ANNEAL
10,000
8000
WAVELENGTH [Å]

FIG. 1

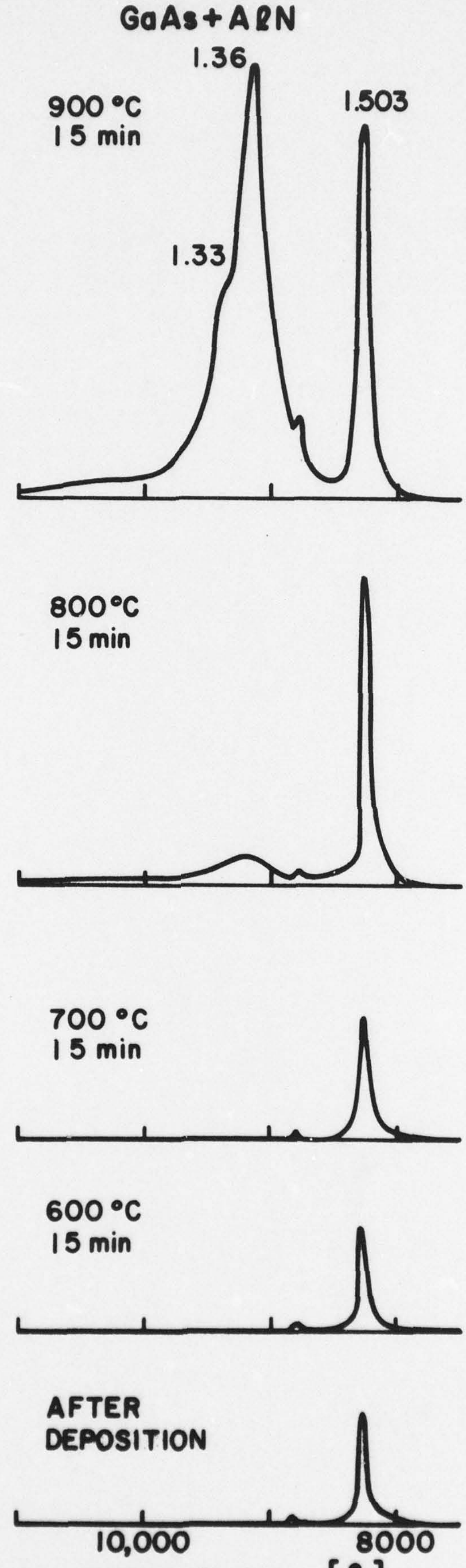
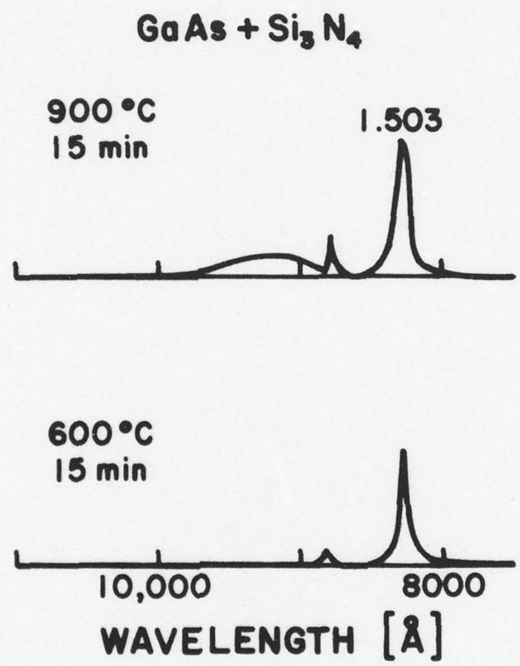

GaAs+AlN
1.36
1.503
900 °C
15 min
1.33
800 °C
15 min
700 °C
15 min
600 °C
15 min
AFTER
DEPOSITION
10,000
8000
WAVELENGTH [Å]

FIG. 2



GaAs + Si_3N_4
900 °C
15 min
1.503
600 °C
15 min
10,000
8000
WAVELENGTH [Å]

FIG. 3

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